Optical Scientific Inc.

OFS-2000 Optical Flow Sensor
40 CFR Part 75 Certification Data

Based on Testing at the 837 Mw
Potomac Electric Power Company (Pepco)
Generating Station in Dickerson, Maryland

Prepared for

Acid Rain Program
Environmental Protection Agency
Washington, DC 20460

By

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Executive Summary

Optical Technology has introduced a revolutionary method of measuring airflow in stacks and ducts using infrared light. Currently available technologies use invasive techniques that place the sensing elements in the harsh environment. Innovative OSi technology allows the measurement to be made through optical windows thereby eliminating the adverse effects of exposure.

The OFS-2000 Optical Flow Sensor has a strong pedigree that includes EPA approved Method 14 flow sensing for MACT compliance in the aluminum smelter industry. The effluent flow from more than 40 smelting pot lines are being measured by the LOA-104 Optical Anemometer. This sensor is designed to measure over very long distances and is ideally suited for the 300-meter long roof vents of the aluminum industry.

The OFS is a completely redesigned sensor intended for the path lengths of 1-10 meters typical of power generating stacks. To prove the design, OSi has undertaken an extensive test program:

NIST Wind Tunnel:

The OFS calibration was established at the National Institute of Science and Technology (NIST). The NIST wind tunnel is the standard by which all anemometers are measured. OSi ran a series of tests up to 40 m/s in the wind tunnel with excellent results. Compared to the NIST Pitot tube standard, the OFS displayed a relative accuracy (as defined by 40 CFR Part 75) of 1.1%.

Pepco Generating Station:

The OFS was installed in the Pepco 837 Mw stack to obtain real world test results. The test program followed the requirements of 40 CFR Part 75, Appendix A. All tests were successfully completed and a relative accuracy of 1.1% was obtained for 10 continuous days of testing against two Part 75 certified ultrasonic sensors.

This report fully documents the methodology and results of this extensive test program. Tables and graphs are included in Appendix B and C, respectively, as supporting documentation.

OFS-2000 Optical Heads

Introduction to OSi and Optical Flow Sensor Technology

Optical Scientific (formerly known as Scientific Technology) is a leading supplier of opto-electronic sensors for meteorological and environmental sensing. Founded in 1985, OSi has pioneered the use of optical scintillation techniques to measure rain, snow, visibility, turbulence, and flow. The Light Emitting Diode Weather Identifier (LEDWI) is used to determine the type and intensity of precipitation at more than 850 airports. The Weather Identifier and Visibility Sensor (WIVIS) is used to determine fog and type and intensity of precipitation at more than 500 road weather stations around the world.

OSi commercialized the technology to measure flow using optical scintillation. One of the largest users of our LOA optical anemometer is the aluminum industry as described below. Other users include universities, military, and government customers. OSi has several unique projects involving optical anemometer technology underway at this time. For the Federal Aviation Administration (FAA) and National Atmospherics and Space Administration (NASA), OSi is developing a sensor to measure wake vortex, a potentially deadly turbulence, at the nation's airports. For the U.S. Army, OSi is developing a miniaturized optical anemometer for sniper rifle crosswind corrections.

With increasing demand for an optical sensor to measure flow over relatively short paths, OSi has developed the OFS-2000. Designed specifically for stacks and exhaust ducts with 1 to 10 meter diameters, the OFS how offers the many features and benefits of optical technology in a small package. Technical information about the OFS is included in Appendix A.

OSi Applicable Experience and Applications

Aluminum Smelter Effluent Velocity

Primary aluminum producers must report the amount of hydrogen fluoride (HF) effluent from their smelters as part of the EPA MACT rules. Traditional propeller anemometers have several known problems including susceptibility to HF & dust-laden air, high temperatures, and lack of representativeness along the typical 300-meter roof vent. OSi developed the Long Baseline Optical Anemometer and Atmospheric Turbulence Sensor Model LOA-104 for use as a flow sensor at aluminum smelters. The LOA measures the path averaged flow using a unique optical technique pioneered by NOAA in the early 1970's. The LOA uses the same 6-inch diameter optics, calibration techniques, and design features originally developed by NOAA.

Optical Scientific (then known as Scientific Technology, Inc.) partnered with the Alcoa Corporation on this project and received Method 14 approval as an alternative method for determining aluminum smelter potroom roof effluent velocity on 9 July 1998. Since that time we have delivered more than 40 systems on 3 continents to the major primary aluminum producers including Alcoa, Reynolds, Kaiser, and Alcan. A copy of the LOA product brochure, worldwide customer list, and EPA approval letter are included in Appendix D.

Chlor-Alkali Plant Effluent Velocity

The chlor-alkali industry uses a process that involves mercury to manufacture chlorine. The EPA developed a program in 1999 to determine the total loss of mercury from a mercury-cell plant. The Olin Corporation facility in Augusta, Georgia was selected as the test site and various equipment manufacturers were contacted to provide equipment for the study. The EPA-NRMRL office in Research Triangle Park, North Carolina contacted OSi concerning the need for reliable roof vent velocity measurements.

To meet the technical challenges of this test, OSi redesigned the optical system of the LOA to allow it to work over the relatively short path of 60 meters. This was accomplished by redesigning the optics from 6-inch to 2-inch, reestablishing the calibration, and other changes. The test, conducted in February 2000, was very successful. Since that time, OSi has sold several LOA systems with 2-inch optics for short path flow monitoring.

Scope of the Document

The remainder of this document details the rigorous series of tests conducted on the OFS-2000. Specifically, the 40 CFR Part 75 was used as the test specification for the OFS. Testing was performed at two locations, the National Institute of Science & Technology (NIST) wind tunnel and the 837 Mw Pepco Generating Station in Dickerson, Maryland.

Each applicable section of Appendix A of Part 75 is detailed in the document. The section begins with a statement of the exact requirement per Part 75. Following each requirement is a description of the compliance of the OFS based on the testing. Detailed tables, graphs, and statistics from the tests are included in the Appendicies as supporting evidence.

Special Acknowledgement

Optical Scientific wishes to express its gratitude to Mr. Keith Felts and Mr. Mickey Lynn of Pepco for the opportunity to test the OFS in real world conditions. They provided technical information, practical suggestions, and encouragement that were invaluable.

40 CFR Part 75 Certification Testing

Part 75, Appendix A – Specifications and Test Procedures Dated January 2000
OFS-2000 Compliance by Section Number

1. INSTALLATION AND MEASUREMENT LOCATION

1.2 Flow Monitors

Requirement: "Install the flow monitor in a location that provides representative volumetric flow…"

OFS Compliance: The OFS is designed to provide representative readings since it is a path-averaging device. Its nominal 4-inch pipe flange mounting design facilitates installation and operation at a location that minimizes swirling, and the effects of condensation, coating, erosion, and other performance affecting conditions.

2. EQUIPMENT SPECIFICATIONS

2.1 Instrument Span

Requirement: "In implementing Sections 2.11 through 2.16 of this Appendix, set the measurement range for each parameter (SO_2, NO_x, CO_2, O_2, or flow rate) high enough to prevent full-scale exceedences from occurring, yet low enough to maintain a high signal to noise ratio. To meet these objectives, select the range… between 20.0 and 80.0 percent of full-scale range of the instrument."

OFS Compliance: The OFS has a full-scale range (span) of 40 m/s or 132 fps. Tests at the PEPCO stack were performed at velocities of 25 to 57 fps (19 to 43 %). OSi believes that the inherent linearity of the OFS as demonstrated by the calibration error testing in Section 3.1 supports that the OFS is accurate anywhere within its span. Performing these tests at 19 to 43 % of the span is identical to testing at 20 to 80 % of the span.

2.1.4 Flow Monitors

Requirement: "Select the full-scale range of the flow monitor so that it is consistent with Section 2.1 of this Appendix and can accurately measure all potential volumetric flow rates at the flow monitor installation site."

OFS Compliance: As stated in Section 2.1, the OFS has a single operating range of 0 to 40 m/s. Due to the linearity of the OFS, this range is more than adequate for typical stack velocities and is not adjustable by the user.

2.2 Design for Quality Control Testing

2.2.2 Flow Monitors

2.2.2.1 Calibration Error Test

Requirement: "Design and equip each flow monitor to allow for a daily calibration error test consisting of at least two reference values: (1) Zero to 20 percent of span… and (2) 50 to 70 percent of span. Flow monitor response, both before and after any adjustment, must be capable of being recorded by the data acquisition by the data acquisition and handling system. Design each flow monitor to allow a daily calibration error test of (1) the entire flow monitoring system, from and including the probe tip (or equivalent) through and including the data acquisition and handling system, or (2) the flow monitoring system from and including the transducer through and including the data acquisition and handling system."

OFS Compliance: The OFS is equipped with a calibration system that operates once per day automatically or upon receipt of an ASCII command from the data acquisition and handling system. The auto calibration test consists of two parts. First, every 3 seconds, the OFS system verifies that the optical alignment and received signal strength are within specification (see 2.2.2.2 Interference Test for further information).

Second, every 24 hours, the OFS injects precise phase shifted frequency pairs that represent 8.75% and 61.5% of span. This methodology is identical to that used with the EPA Method 14 Approved LOA for aluminum smelters.

During the calibration, byte 42 of the ASCII data string changes from 0 to 4 to alert the data acquisition and handling system that calibration is underway. Data from each calibration point is compared to the standard value and automatically compared to the correct value. Calibration values outside the range of +/- 3% of the standard value are registered as a "fail" and an error flag (byte 43 set to 4 or 5) is sent to the user as part of the normal ASCII data string. In addition, the failure causes the velocity field in the ASCII data string to be blanked out with "------" to prevent bad data from being reported. The total auto-calibration cycle time is < 2 minutes.

2.2.2.2 Interference Test

Requirement: "Design and equip each flow monitor with a means to ensure that the moisture expected to occur at the monitoring location does not interfere with the proper functioning of the flow monitoring system. Design and equip each flow monitor with a means to detect, on at least a daily basis, pluggage of each sample line and sensing port, and malfunction of each resistance temperature detector (RTD), transceiver, or equivalent."

OFS Compliance: The OFS-2000 is equipped with several mechanisms to monitor, detect, and report interference from moisture and/or dust. First, the OFS is designed to operate over a wide 40 dB dynamic range of received light levels. This feature enables the OFS to operate in the harsh environment of a stack. Once every three (3) seconds, the OFS measures the amount of light received by the two (2) optical detectors. A self-test algorithm in the OFS compares the received light levels (i.e. voltages) to a fixed range of acceptable values. If the voltages are in the range of 0.1 to 9.98 volts, the self-test is registered as a "pass". If the voltages are outside this range, the self-test is registered as a "fail" and an error flag (byte 42 set to 1, 2, or 3) is sent to the user as part of the normal ASCII data string. In addition, the failure causes the velocity field in the ASCII data string to be blanked out with "------" to prevent bad data from being reported. Figure 1 shows the received signal strength (light level) from the 2 optical detectors for a 10-day test period at Pepco and a comparison of the LOA velocity with the 2 Pepco ultrasonic flow sensor velocities. As shown, the A & B receive signal strength experienced only minor fluctuations during the test period.

Second, the OFS front mounting flange is equipped with standard ¼ NPT fittings to allow the user to connect clean, dry, oil-free factory air to purge the optical windows. The introduction of purge air has no effect on the flow measurement and is similar to that used with the EPA Method 14 Approved LOA for aluminum smelters.

3. PERFORMANCE SPECIFICATIONS

3.1 Calibration Error

Requirement: "The calibration error performance specifications in this section apply only to 7-day calibration error tests under Sections 6.3.1 and 6.3.2 of this Appendix… The calibration error of flow monitors shall not exceed 3.0 percent of the calibration span value of the instrument, as calculated using Eq. A-6 of this Appendix."

OFS Compliance: A 7-day test was performed in accordance with Section 6.3.2. Calibration was performed every 24 hours at two points, low (0-20% span) and mid (50-70% span). The table calculates the calibration error (CE) for each data point using Eq. A-6 using a span of 40 m/s. The calibration error, computed to be <0.1%, is well within the required tolerance of 3%. The data is shown in the Appendix as Table 1.

3.3 Relative Accuracy

3.3.4 Relative Accuracy for Flow

Requirement: "Except as noted below in this section, relative accuracy of flow monitors, where volumetric gas flow is measured in scfh, … the relative accuracy of flow monitors shall not exceed 10.0 percent. For affected units where the average of the flow monitor measurements of gas velocity during one or more operating levels of the relative accuracy test audit is less than 10.0 fps, the mean value of the flow monitor velocity measurements shall not exceed +/- 2.0 fps of the reference method mean value in fps wherever the relative accuracy specification above is not achieved."

OFS Compliance: The relative accuracy was tested in two ways. First, the OFS was calibrated at the National Institute of Science and Technology (NIST) wind tunnel using the NIST calibrated Pitot tube sensor as the standard. Figure 2 is a graph of the data obtained when the OFS was compared to the NIST standard over a range of 0 to 40 m/s. The relative accuracy from the NIST wind tunnel test was determined using the procedure in Section 7.3. From Eq. A-10, the relative accuracy using the NIST wind tunnel as a standard is 1.09 %, well within the 10% requirement. The test data and statistics are provided in Table 2.

Second, the OFS was installed at the Pepco stack at the same location as two Part 75-approved ultrasonic flow sensors for 10 days. For the relative accuracy test, the hourly OFS velocities were compared to the average of the two ultrasonic velocities using the procedures in Section 7.3. The data and graphs for the 10 summary are shown in the Appendix as Table 3 and Figure 3. From Eq. A-10, the relative accuracy using the mean ultrasonic velocity as a standard is 1.11 %, well within the 10% requirement.

The data and graphs for the 10 individual days are shown in the Appendix as Tables 4-13 and Figures 4-13. The relative accuracy for each individual was also well within the 10% Part 75 requirement.

3.4 Bias

3.4.2 Flow Monitors

Requirement: "Flow monitors shall not be biased low as determined by the test procedure in Section 7.6 of this Appendix. The bias specification applies to all flow monitors including those measuring an average gas velocity of 10.0 fps or less."

OFS Compliance: Tests at the Pepco stack never decreased to velocities below 10 fps therefore it was not possible to test for bias in a stack. However, to demonstrate the OFS linearity, the bias performance of the OFS was calculated using the NIST Wind Tunnel data set as described in Section 7.6. The table calculates the statistics for the data using Eq. A-7, A-8, and A-9. The mean difference, $\overline{d}$ (0 fps) is less than the absolute value of the confidence coefficient, cc (0.23 fps), therefore the OFS passes the bias test and no bias adjustments are required. The data is shown in the Appendix as Table 2.

4. DATA ACQUISITION AND HANDLING SYSTEMS

Requirement: "Automated data acquisition and handling systems shall (1) Read and record the full range of pollutant concentration and volumetric flow from zero through span; and (2) provide a continuous, permanent record of all measurements and required information as an ASCII flat file…"

OFS Compliance: Data acquisition and handling is the responsibility of the end user but the OFS is designed to facilitate the requirements. The output of the OFS is an ASCII serial data string that contains information on flow velocities, calibration errors, self-test results, and other data. The users data acquisition and handling system will acquire the OFS data once per minute (typical) and compute volumetric flow rates, record data, and other functions as required.

APPENDIX A

OFS-2000 Optical Flow Sensor

Product Brochure
Press Release
Beta Test Results & Info Sheet
PowerPoint Presentation

APPENDIX B

Tables

7-Day Calibration Error Test Data & Statistics
NIST Wind Tunnel Data & Statistics
10-Day Pepco Test Data & Statistics Summary
Daily Pepco Test Data & Statistics (10 days)

APPENDIX C

Figures

10-Day Interference Test Graph
NIST Wind Tunnel Graph
10-Day Pepco Relative Accuracy Summary Graph
Daily Pepco Relative Accuracy Summary Graphs (10 days)

APPENDIX D

LOA-104 Optical Anemometer

Product Brochure
Worldwide Installation list
EPA Alternative Method Approval Letter

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